Development, Implementation, and Testing of a Comprehensive Method for Integrating Acoustic Observations into Dynamic Ocean Models to Provide Enhanced Ocean Analysis and Prediction Capabilities for Undersea Warfare

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LONG-TERM GOALS

Develop technology to perform ocean acoustic tomography in littoral regions that can be utilized to improve the nowcasts and forecasts of ocean circulation models of the regions.

OBJECTIVES

Research, develop, test, and implement some of the various software processing packages that are required for model-oriented acoustic tomography based on data collected from bottom-mounted acoustic nodes operating at frequencies from 8-12 kHz. Specifically, develop an automated system for computing (and recomputing) the error covariance matrices required of a data assimilation scheme for ocean acoustic tomography.

APPROACH

Our approach was to develop a modular system of software written in FORTAN90. The elements of the software were developed to be executed using a script file, with elements of data and calculation results passed with files with specific naming conventions. Modules for reading required outputs from ocean models can be readily modified for different organization archive formats. The software format was developed to execute in an automated fashion via the script file, requiring no man-in-the-loop.

Key individuals participating in this work at SSI were Drs. J. K. Lewis (overall system programming, ocean model expertise) and S. Rajan (acoustic modeling).

WORK COMPLETED

In a formulation detailed by Lewis et al. (*J. Acoust. Soc. Am.*, June, 2005), a method for ingesting acoustic observations into dynamic ocean models was presented. This method utilized a version of the Physical-Space Statistical Analysis System (PSAS) for using travel time information between a source and receiver to modify the predicted temperatures, salinities, and velocities in a hydrodynamic ocean

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14. ABSTRACT

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model of the region in which the source and receiver were located. This technology has been given the name of the "Coupled Oceanographic-Tomographic Analysis and Prediction System": *COTAPS*.

The PSAS method calculates a Kalman gain that is a function of the spatial error covariance matrices of the ocean model and the observed travel times. The basic task for this project extended the methodology for calculating the Kalman gain that included impacts of temperature, salinity, velocity, and errors in the observations and codify the method in a FORTRAN90 program. As opposed to having the code as a stand-alone computer program, additional software was developed to create a package of programs that allows users to define the critical aspects of a tomographic domain, interface information about that domain with an acoustic propagation model, interface the results of the propagation model with an ocean circulation model of the domain, and then generate a Kalman gain for use by the ocean model to assimilate acoustic travel time data. We refer to this software package as *COTAPS*-V1. *COTAPS*-V1 is set up to allow users to update acoustic path characteristics and the Kalman gain as required. For example, if internal tides substantially modify the path characteristics or error covariance matrices, *COTAPS*-V1 can be executed every 3 or 4 days to account for this tidal influence.

RESULTS

The software package contains a component that can be used to determine the characteristics of acoustic rays between up to 300 pairs of sources and receivers within the domain of an ocean circulation model. Characteristics include the ray path through the water column and arrival times. The component utilizes the Bellhop acoustic propagation model. The significance of this component is that there now exists software that can be used to determine critical acoustic ray characteristics relative to the domain of an ocean circulation model.

Other components of the software package use the output from the ray path characterization component and the three-dimensional grid cell structure of the ocean model to calculate parameters for individual grid cells related to the PSAS assimilation scheme. This is a critical piece of software in that it generates those files and variable values that are utilized in calculating the Kalman gain.

The final component of the software package is the routine that calculates the Kalman gain. This is the critical software that takes the procedures detailed in Lewis et al. and transcribes the matrix expressions and formulations into a functional computer code. Computational and computer storage requirements have been determined for this computer code (the calculation of the model error covariance matrix can be substantial). Inputs come from the previous software components, and the output file is used directly by the ocean model of the region in question by the PSAS code in the ocean model.

The software package provides a new capability to readily characterize acoustic ray paths in ocean model domains and calculate a PSAS Kalman gain in order to utilize tomographic measurements in the ocean model.

IMPACT/APPLICATION

The work performed here establishes the framework for the operational use of tomographic measurements to improve nowcasts and forecasts for ocean circulation models. Additional research is required to answer some questions concerning details of tomographic measurements that would feed

into the software package. However, this software package makes a huge step forward in making operational use of tomography a reality. The use of bottom-mounted acoustic sources and receivers also provides a covert mode of operation for tomography, which could be an important factor for Navy needs.

RELATED PROJECTS

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PUBLICATIONS

Lewis, J. K., J. Rudzinsky, S. Rajan, P. J. Stein, and A. Vandiver, 2005: Model-oriented ocean tomography using higher-frequency, bottom-mounted hydrophones. *J. Acoust. Soc. Am*, 117(6), 3539-3554. [published, refereed]